Use of Satellite Observations in SMAP Cal/Val

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Overview

- SMAP data products
- Relevant Microwave satellites
- L1 data cal/val
- L2+ data cal/val
- Aquarius Soil Moisture
- SMOS/SMAP data in cal/val rehearsal

SMAP Data Products

Data Product Short Name	Short Description	Gridding (Resolution)	Latency*
L1A_Radar	Radar raw data in time order	-	12 hours
L1A_Radiometer	Radiometer raw data in time order	-	12 hours
L1B_S0_LoRes	Low resolution radar σ_o in time order	(5x30 km)	12 hours
L1B_TB	Radiometer T_B in time order	(36x47 km)	12 hours
L1C_S0_HiRes	High resolution radar σ_o (half orbit, gridded)	[illegible]	[illegible]
L1C_TB	Radiometer T_B (half orbit, gridded)	36 km	12 hours
L2_SM_A	Soil moisture (radar, half orbit)	3 km	24 hours
L2_SM_P	Soil moisture (radiometer, half orbit)	36 km	24 hours
L2_SM_A/P	Soil moisture (radar/radiometer, half orbit)	[illegible]	[illegible]
L3_F/T_A	Freeze/thaw state (radar, daily composite)	[illegible]	[illegible]
L3_SM_A	Soil moisture (radar, daily composite)	3 km	50 hours
L3_SM_P	Soil moisture (radiometer, daily composite)	36 km	50 hours
L3_SM_A/P	Soil moisture (radar/radiometer, daily composite)	9 km	50 hours
L4_SM	Soil moisture (surface & root zone)	[illegible]	[illegible]
L4_C	Carbon net ecosystem exchange (NEE)	[illegible]	[illegible]

Instrument data

Science data

Value added data

* Mean latency under normal operating conditions (defined as time from data acquisition by the observatory to availability to the public data archive). The SMAP project will make a best effort to reduce these latencies.

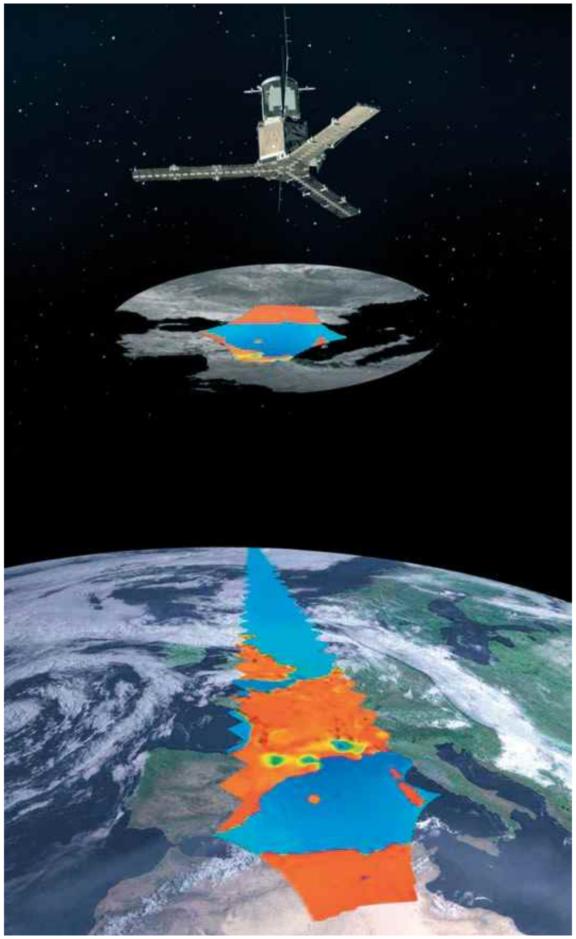
** Over outer 70% of the swath.

Overview

- SMAP data products
- Relevant Microwave satellites
  - SMOS
  - Aquarius
  - GCOM-W
  - SAOCOM
  - ALOS-2
- L1 data cal/val
- L2+ data cal/val
- Aquarius Soil Moisture
- SMOS/SMAP data in cal/val rehearsal

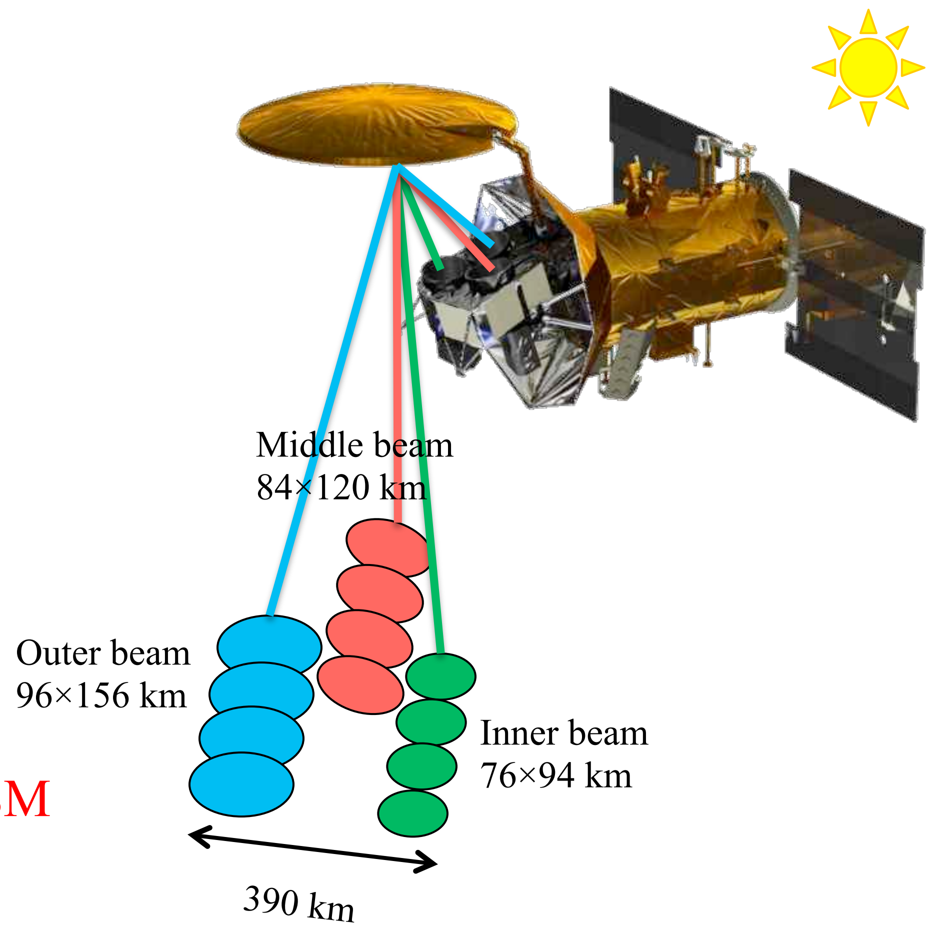
SMOS

- Passive microwave L-band 2D-synthetic aperture launched by ESA in Nov 2009
  - Multiple incidence angles (0-60 degrees) at every location along the swath
- Sun Synchronous orbit with an Ascending orbit of 6:00 AM
- Spatial resolution 40 km
- 3 day global coverage
- Provides L1 TB and L2 SM



Aquarius/SAC-D

- Mission (NASA and CONAE)
  - Sun-synch orbit [6 am (Des.)]
  - Night time look direction
  - 657 km Alt; 7 day revisit
  - Launch: June 2011
- Aquarius Instrument
  - L-band Polarimetric
  - Radiometer and Scatterometer
  - 3 Beam Pushbroom
  - Incidence angles of 29.36°, 38.49°, and 46.29°
- Provides L1 TB, sigma and L2 SM
- SAC-D
  - MWR (8 beams at 37 GHz)
  - Other

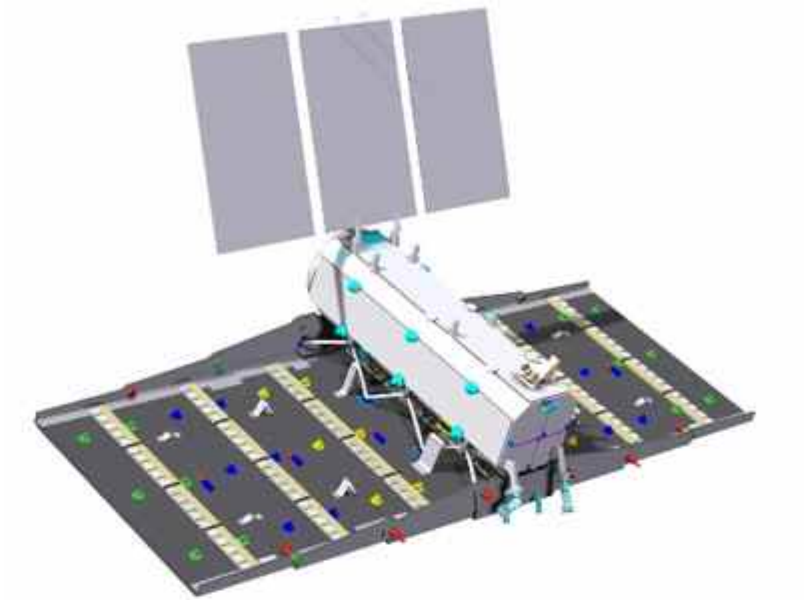


GCOM-W/AMSR2

- Successor to AMSR-E
- Launched by JAXA in 2012
- Sun Synchronous orbit with an Ascending orbit of 1:30 PM (A-train)
- Frequencies
  - 6.925, 7.32 (C-band), 10.65 (X-band), 18.7, 23.8, 36.5, 89.0 GHz
- Provide a long term climate data record for brightness temperature and soil moisture (along with AMSR-E)
- Swath – 1400 km
- 3 day global coverage
- Provides L2 SM

SAOCOM

- Consists of SAOCOM-1 (launch 2014) and SAOCOM-2 (launch 2015)
- L-band SAR
- Resolution of 7m to 100 m
- Swath width of 50 km to 400 km
- Revisit time of 16 days
- Provides L1 sigma and L2 SM
- Details presented previously



ALOS-2

- Follow-on to the ALOS mission
- L-band SAR developed by JAXA
- Descending overpass of 12 noon
- Resolution of 1 m to 100 m
- Swath width of 25 km to 350 km
- Revisit time of 14 days
- Provides L1 sigma and L2 SM

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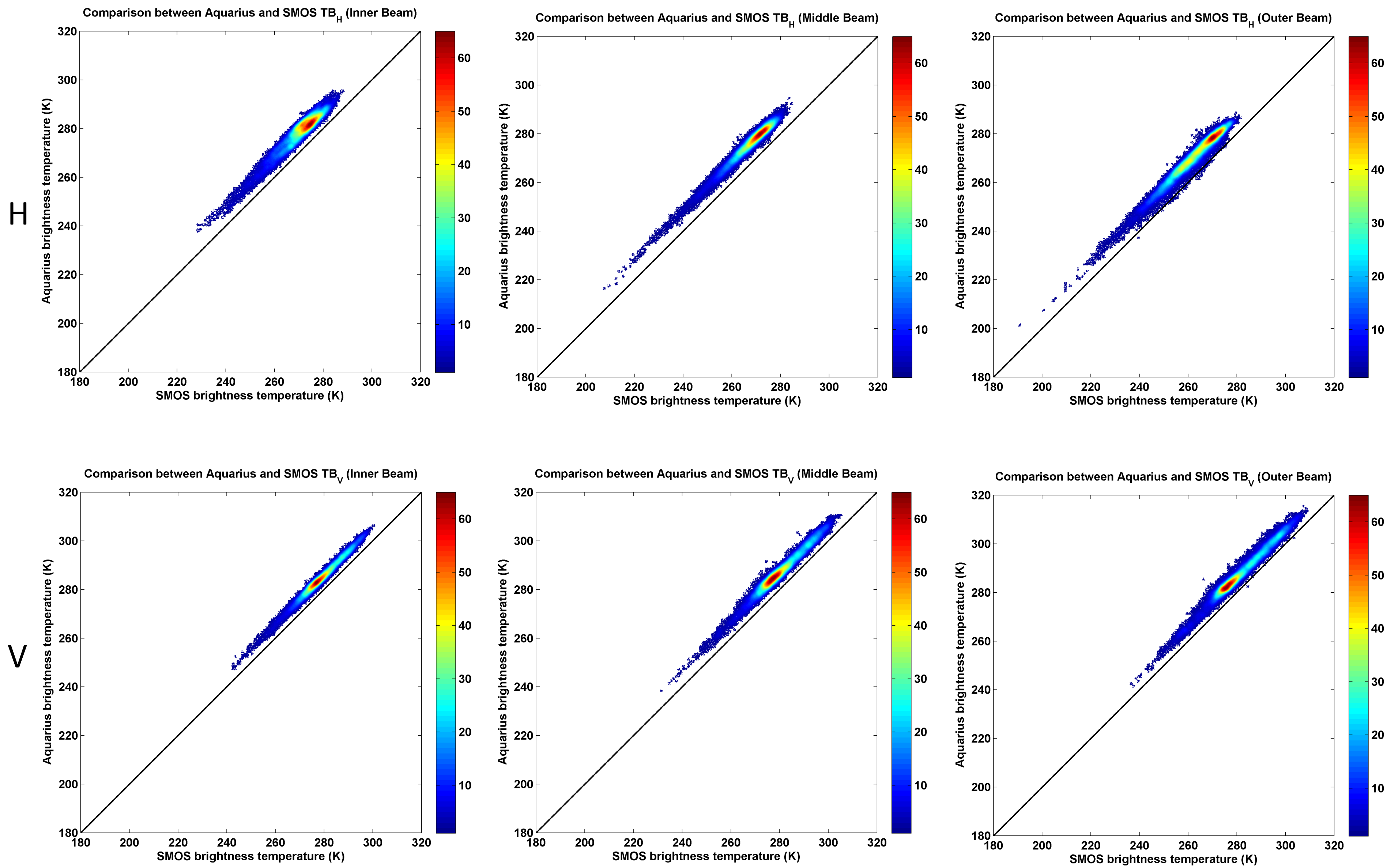
Need for satellite inter-calibration

- On orbit inter-comparison of multiple L-band radiometers
- Need for consistent observations:
  - SMAP, Aquarius and SMOS provide an opportunity to check each others calibration
  - Critical to develop a long-term climatic data record of L-band brightness temperature observations
  - A physical algorithm for development of a long term environmental data record that spans multiple L-band missions requires consistent input observations

Inter-comparison example (Aquarius and SMOS)

- Recognize that during Cal/Val that there will be some possible calibration issues and to check if the data is consistent with other L-band observations
- Approach: Use L-band satellite observations from multiple satellites as a tool in assessing the calibration of the SMAP radiometer
- Concurrent observations in both time (within 30 min → eliminates effect of change in physical temperature) and space (same location)
- Aquarius and SMOS inter-comparison notes
  - Aquarius evaluation Version 1.3.5
  - Period of record : August 25, 2011 – August 31, 2012
  - Land and ocean
  - Concurrent SMOS and Aquarius observations within 30 min (results in data only between latitudes ~[40, -20])
  - Same incidence angle (after re-processing SMOS data)
  - Only alias free portions of SMOS observations
  - Multiple SMOS DGG locations within a single Aquarius footprint
  - Min number of SMOS observations per Aquarius footprint required– 20 (to minimize partial Aquarius footprint coverage)
  - Std. Dev. of SMOS data averaged < 5 K (land) and 1 K (ocean) (to minimize footprint variability; also results in screening RFI)
  - Differences in azimuth angle and orientation of the footprints ignored

Comparison between Aquarius and SMOS over Land



Comparison between Aquarius and SMOS over Land

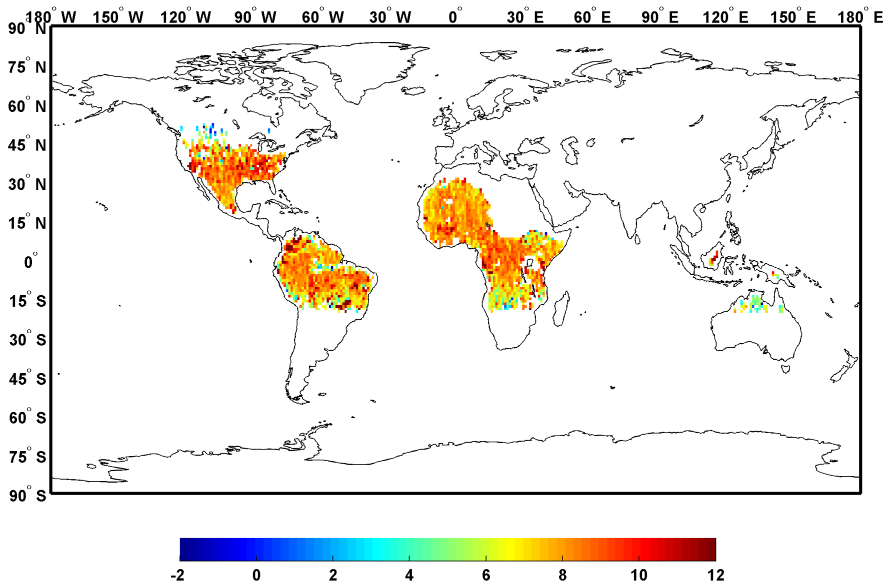
Summary Statistics

		RMSD (K)	R	Bias [Aq-SMOS] (K)
H pol	Inner (29.36^{o})	8.47	0.9697	8.16
	Middle (38.49^{o})	8.50	0.9851	8.32
	Outer (46.29^{o})	8.10	0.9787	7.76
V pol	Inner (29.36^{o})	6.03	0.9906	5.89
	Middle (38.49^{o})	7.27	0.9848	7.04
	Outer (46.29^{o})	6.68	0.9853	6.38

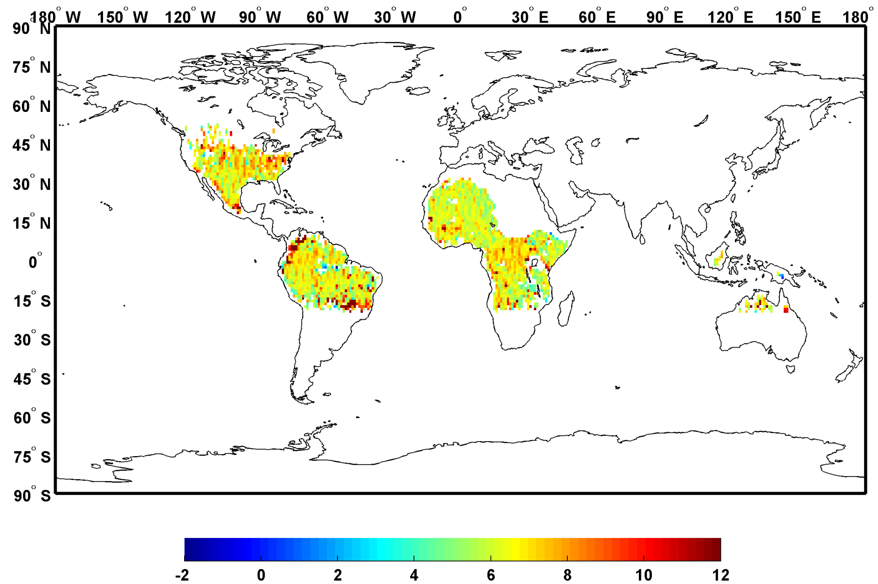
Comparison Between Aquarius and SMOS over Land

- RFI regions were screened out of the analysis
- All channels show a bias between SMOS and Aquarius observations
- H-pol bias greater than V-pol bias for all beams
- Middle beam (38.49^o) has more scatter than the inner beam (29.36^o)
- Outer beam has the most scatter and outliers
- H-pol TB decreases with increase in incidence angle and vice versa for V-pol (consistent with expected behavior).

Δ Tb_H between Aquarius and SMOS (All Beams)



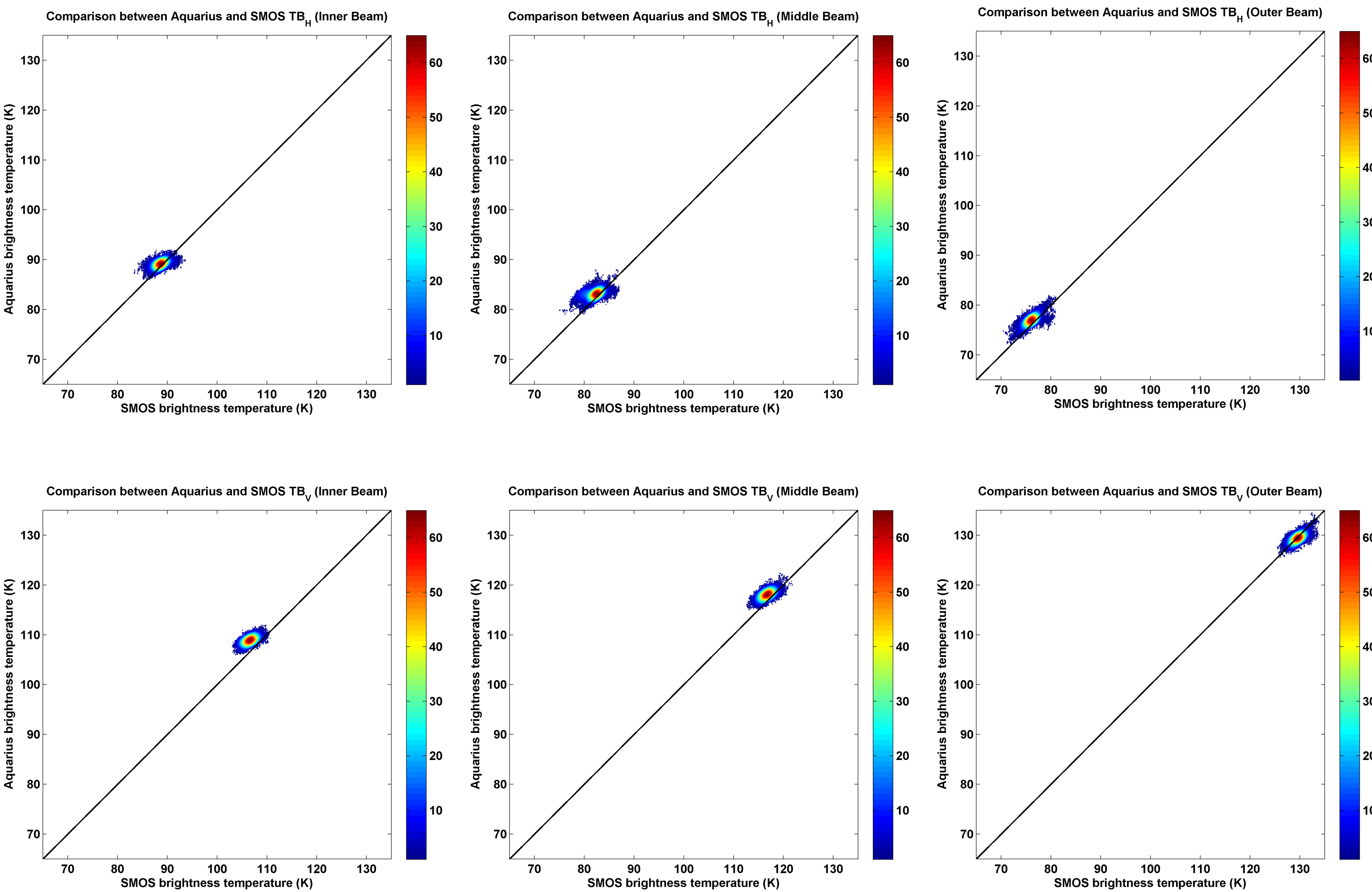
Δ Tb_V between Aquarius and SMOS (All Beams)



Comparison between Aquarius and SMOS over Ocean

H

V

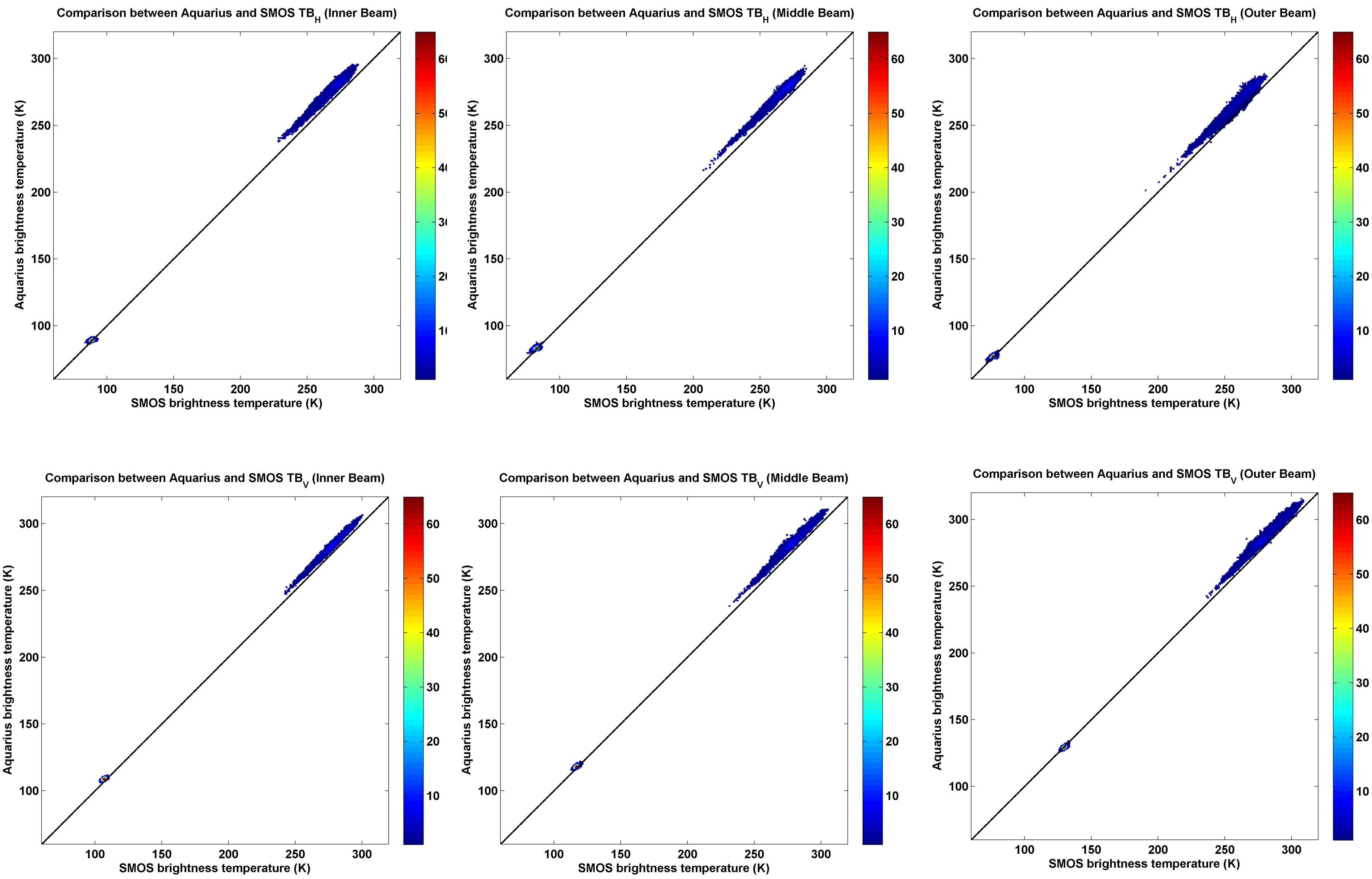


Comparison between Aquarius and SMOS over Ocean

Summary Statistics

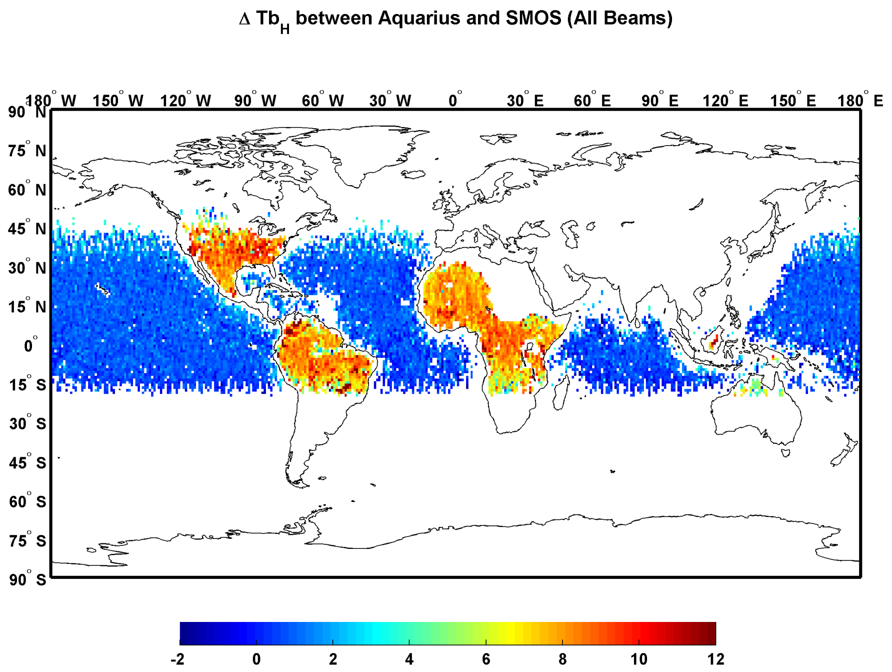
		RMSD (K)	R	Bias [Aq-SMOS] (K)
H pol	Inner (29.36^o)	1.10	0.5600	0.57
	Middle (38.49^o)	1.64	0.4830	1.06
	Outer (46.29^o)	1.22	0.7480	0.93
V pol	Inner (29.36^o)	2.49	0.5873	2.33
	Middle (38.49^o)	1.62	0.6225	1.36
	Outer (46.29^o)	0.79	0.6988	-0.18

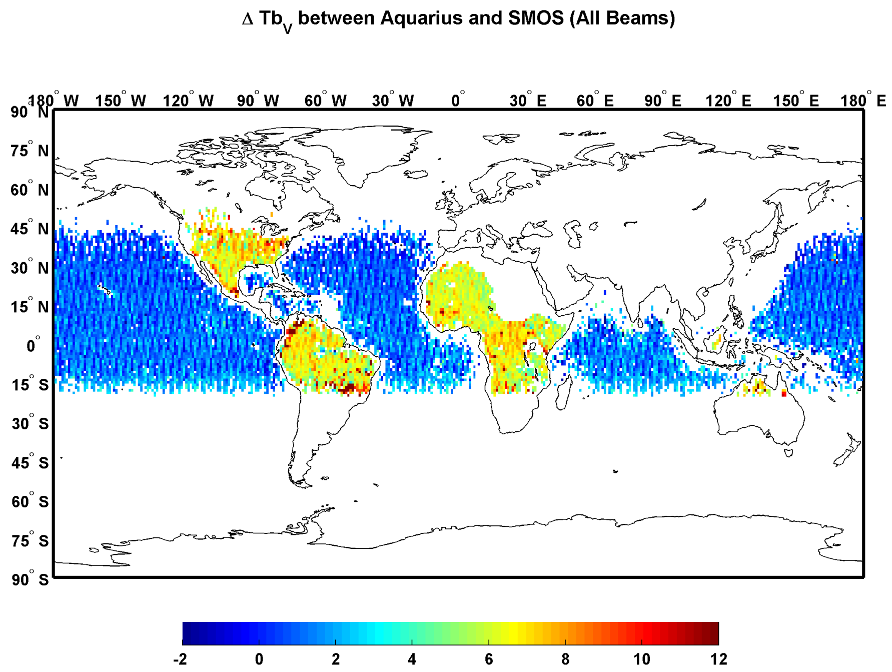
Comparison between Aquarius and SMOS



Comparison between Aquarius and SMOS

- Intercomparison results:
  - SMOS and Aquarius compare well over oceans
  - Very high correlation between SMOS and Aquarius observations
  - Systematic difference in gain and offset for all channels
  - expecting improvements in future versions
- Scatter possibly due to:
  - RFI (possible RFI in SMOS/Aquarius)
  - Heterogeneous footprint
  - Different azimuth angles
  - Noise in SMOS data





Inter-comparison summary

- Aquarius data calibration has focused on ocean observations through the cal/val phase
- Aquarius observations compare well with SMOS observations over oceans
- Scatter due to:
  - RFI (possible RFI in SMOS/Aquarius)
  - Heterogeneous footprint
  - Different azimuth angles
  - Noise in SMOS observations
- Aquarius observations very stable
- SMOS observations lower than Aquarius observations for all channels over land
- Aquarius team advisory: The data has been validated over oceans but not land

Overview

- SMAP data products
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- L1 data cal/val
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L2 data cal/val using Multiple Satellites

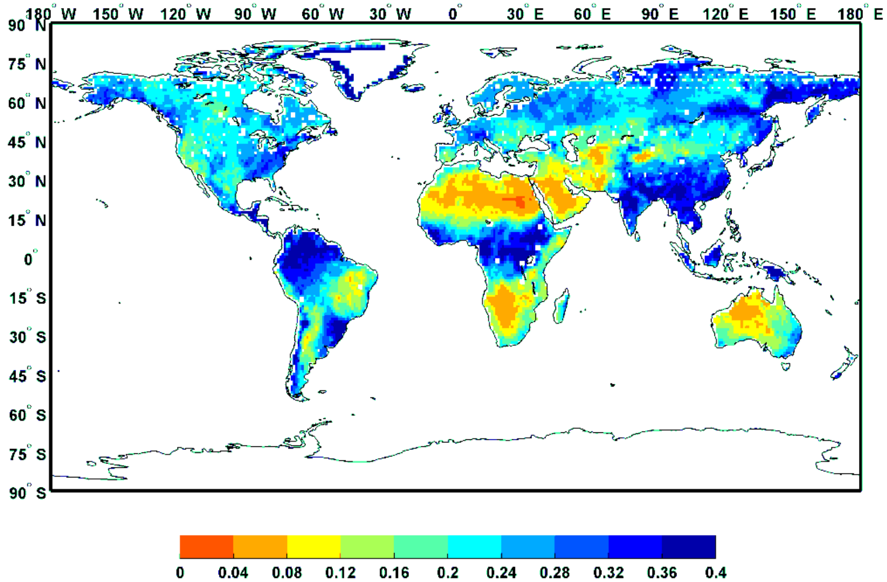
- Satellite VSM products provide a global comparison
- In situ data can provide validation resources over a limited domain
- Provide a tool to evaluate the spatial and temporal consistency
- Spatial resolution compatible with SMAP products

L2 data cal/val using Multiple Satellites

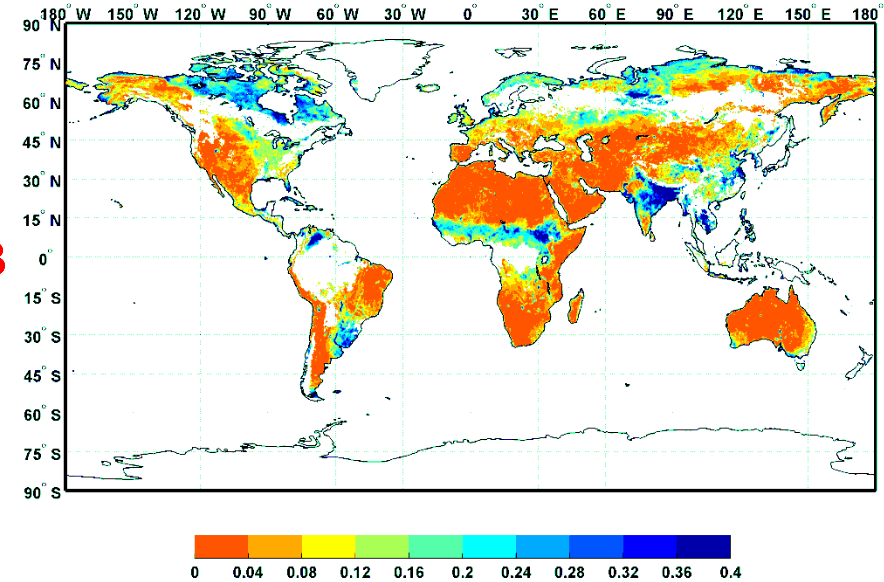
- Multiple Soil Moisture satellite products
  - SMOS
  - Aquarius
  - SMAP
  - GCOM-W
- SMOS, GCOM-W and Aquarius products should be mature by SMAP launch
- These missions have independent resources for their cal/val activities (possible to leverage resources)
- Model products from GMAO, NCEP, ECMWF

Four Global Soil Moisture Products (Sept. 2011)

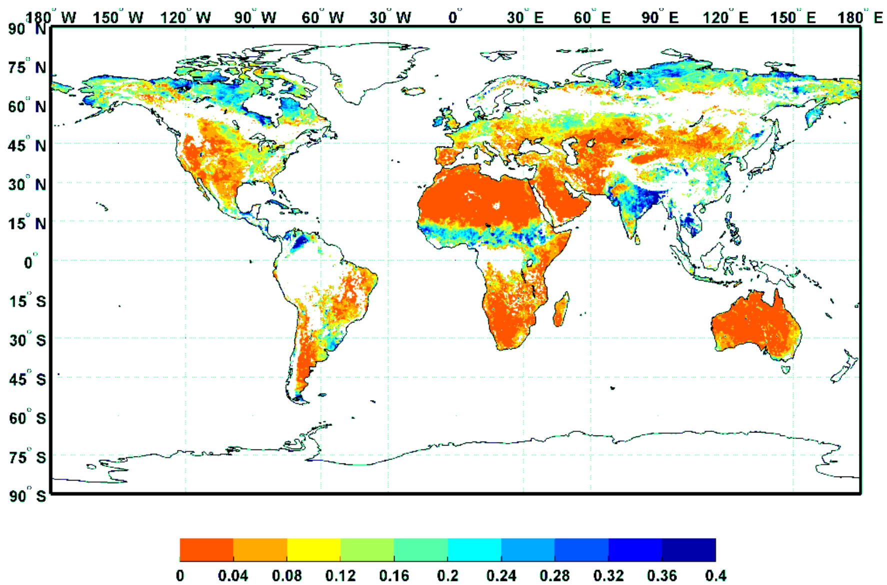
A



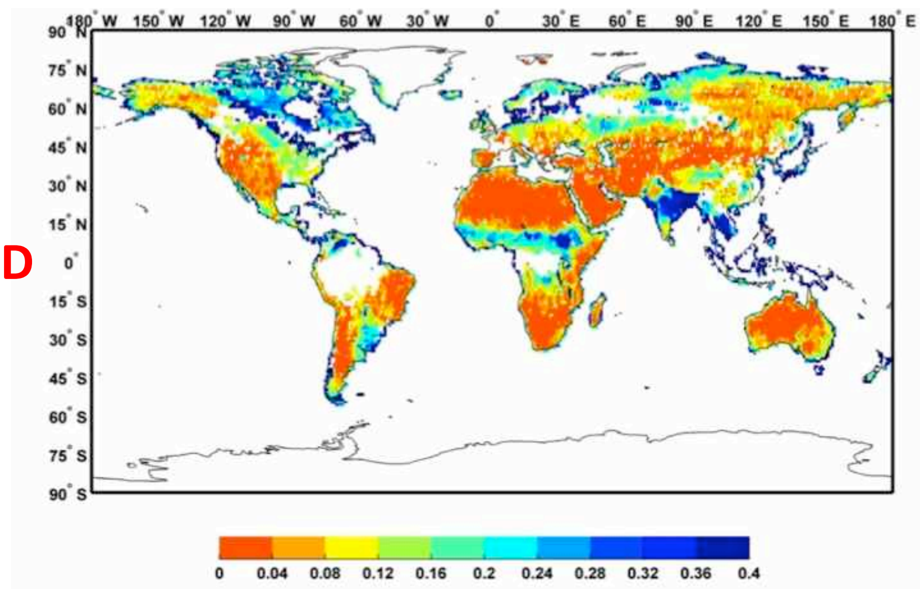
B



C



D



D Aquarius Soil Moisture (SCA)

A NCEP Soil Moisture

C SMOS Soil Moisture (L2 data)

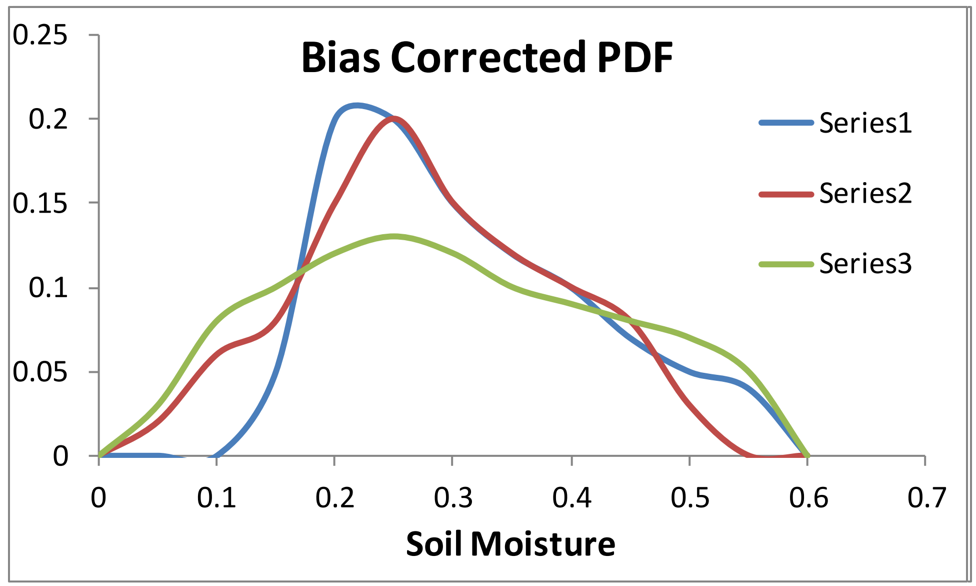
B SMOS/SMAP SCA Soil Moisture

L2 data cal/val

- Error (RMSE) $$RMSD = \sqrt{\frac{\sum (x-y)^2}{N}}$$
- Bias $$Bias = \frac{\sum (x-y)}{N}$$
- Unbiased RMSE $$\boldsymbol{uRMSE = \sqrt{RMSE^2 + Bias^2}}$$
- Correlation Coefficient $$r = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sigma_x \sigma_y}$$
- Triple Collocation
  - Error estimates between independent datasets

L2 data comparison

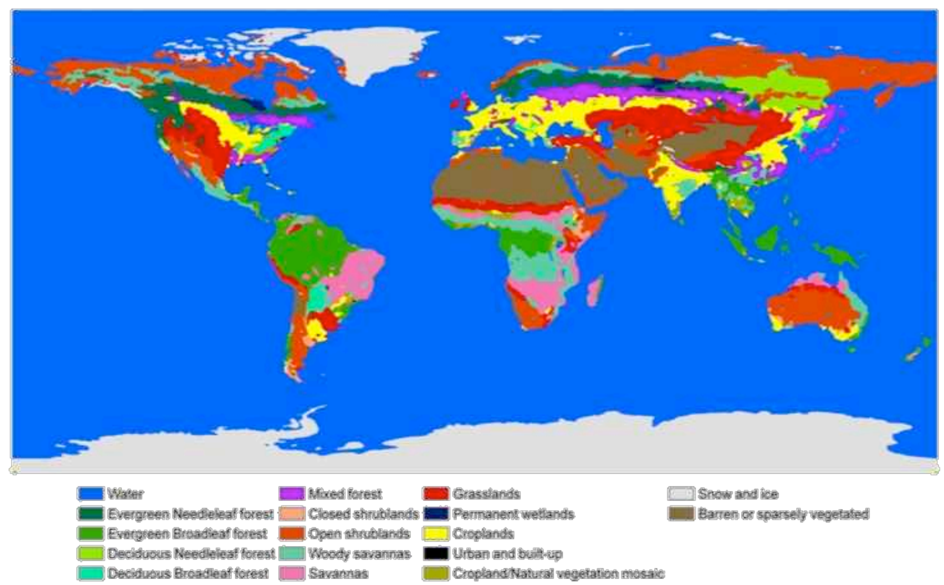
- Mean, Std. Dev, Skewness, Kurtosis
- Global data
- Unmodified product, Bias corrected
- Climatological Comparisons



Comparison between Soil Moisture products

- Geographically
- Vegetation classes
- Seasons
- Comparison metric
  - RMSD
  - Correlation coefficient
  - Bias
- Bias corrected?
- Climatology corrected?

IGBP Land Cover



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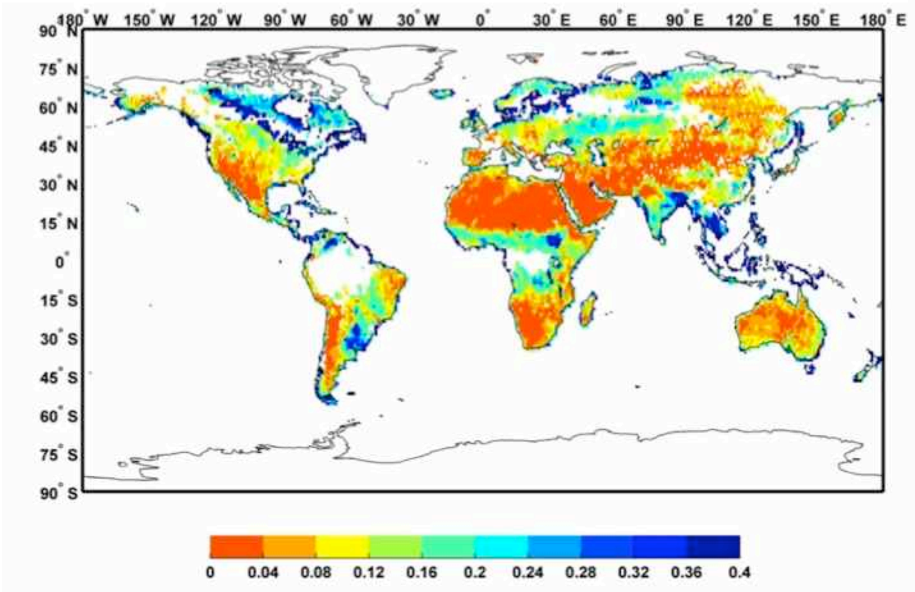
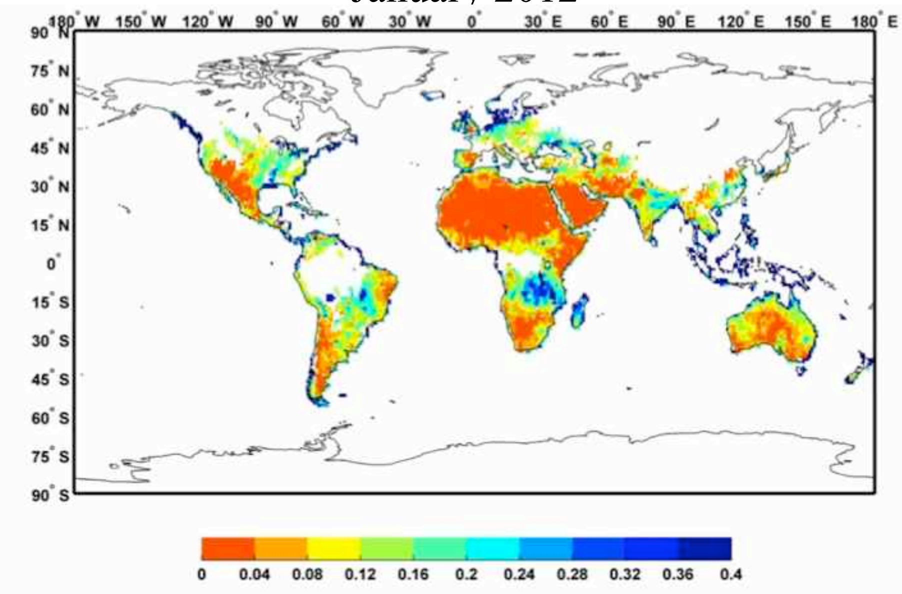
Monthly Aquarius Soil Moisture

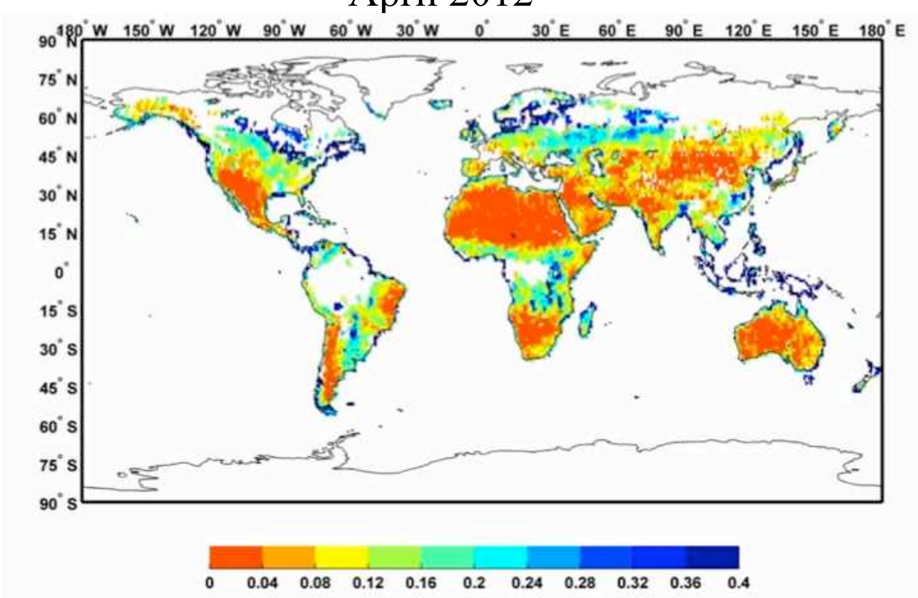
October 2011



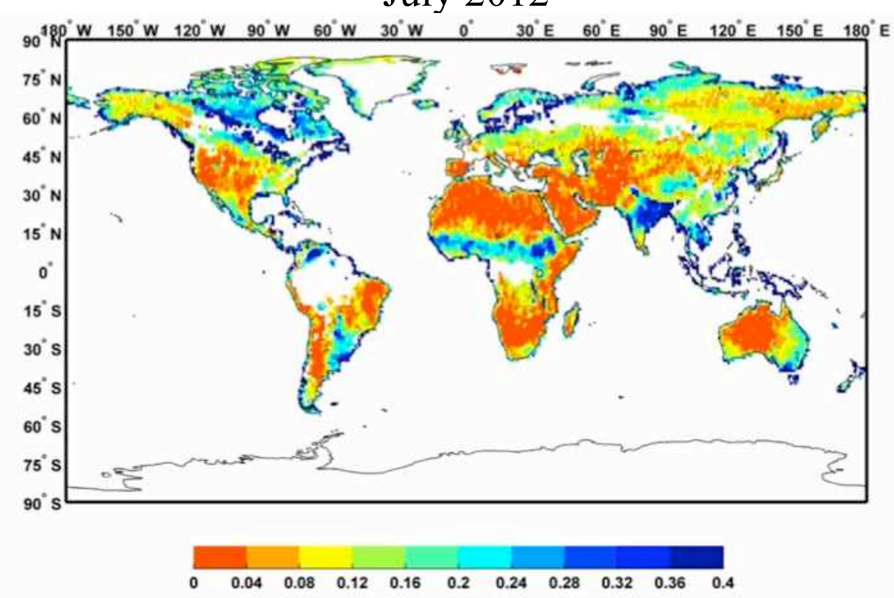
January 2012



April 2012

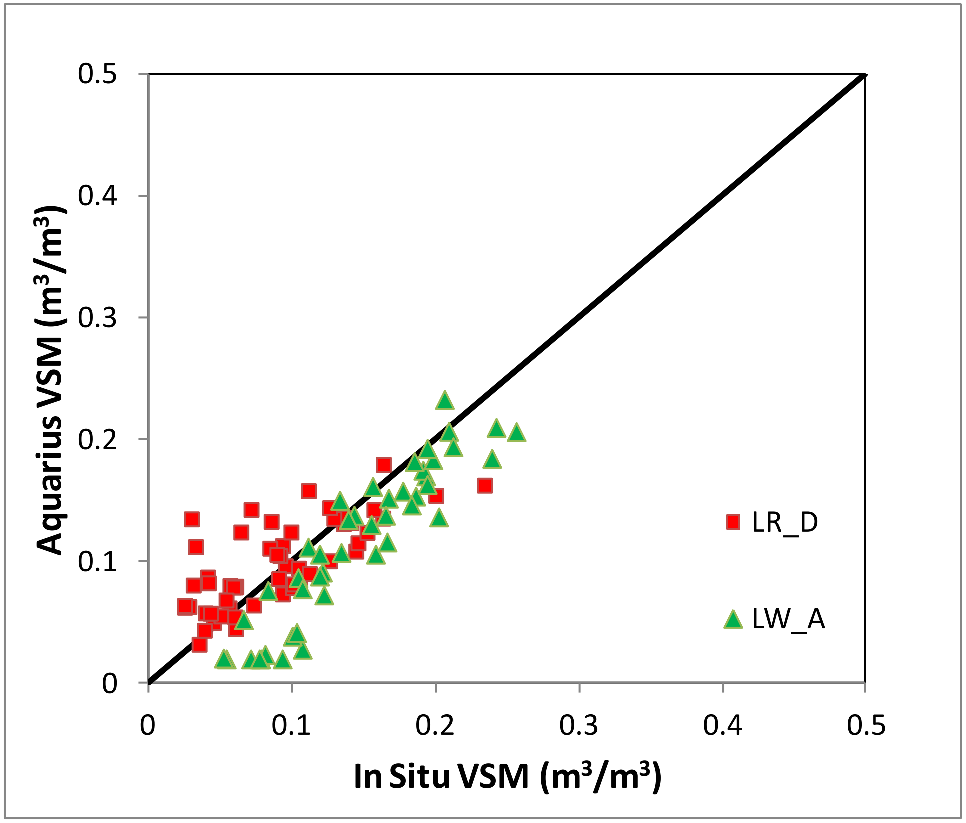


July 2012



Validation Results

- SCA algorithm (SMAP L2_SM_P baseline) used in Aquarius VSM
- Aquarius soil moisture compare well with in situ observations
- Validation was limited to LW and LR due to the size of Aquarius footprint.
- Incidence angle effects removed in Aquarius VSM
- RMSE ~ 0.036 m^3/m^3, Bias ~ 0.008 m^3/m^3



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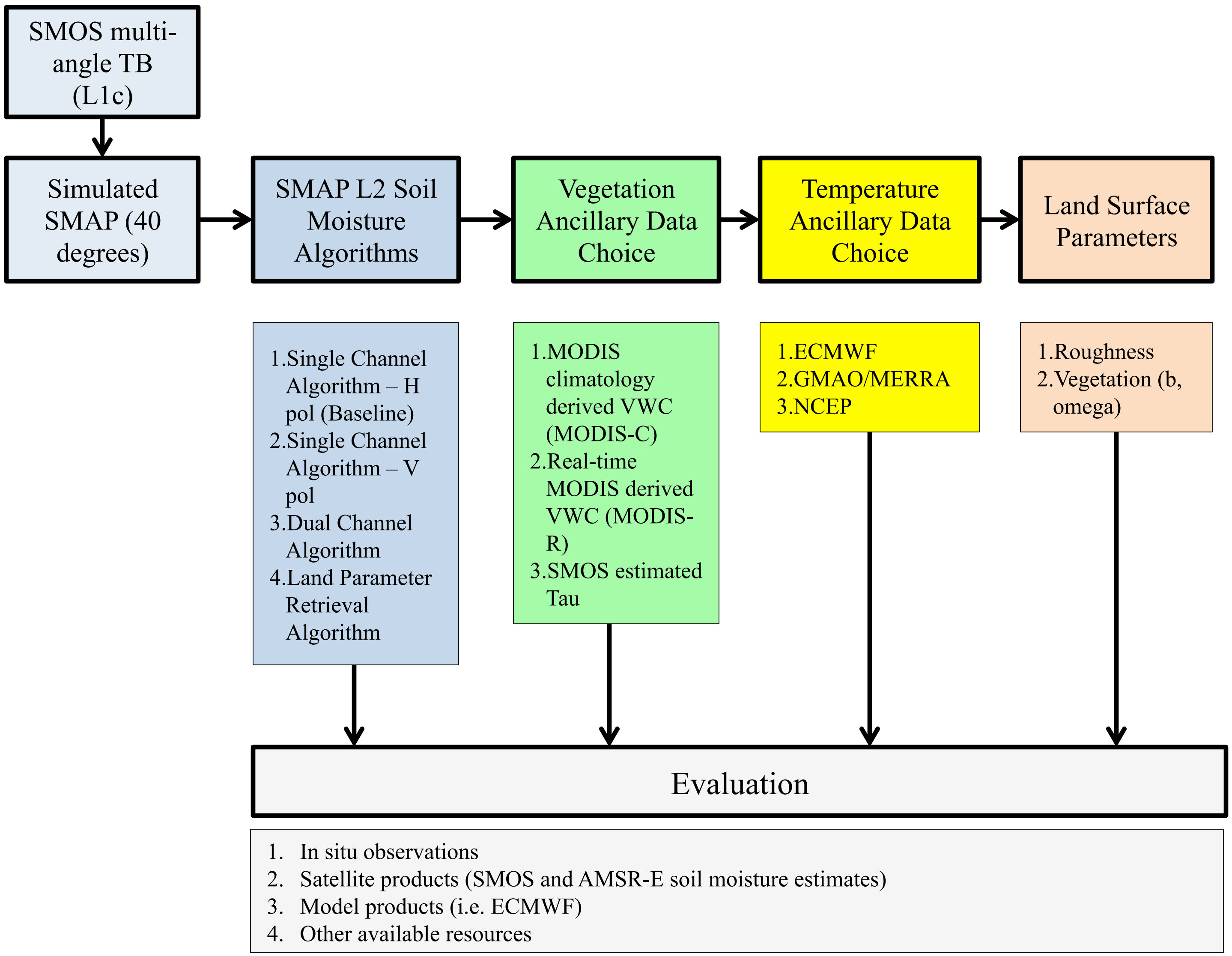
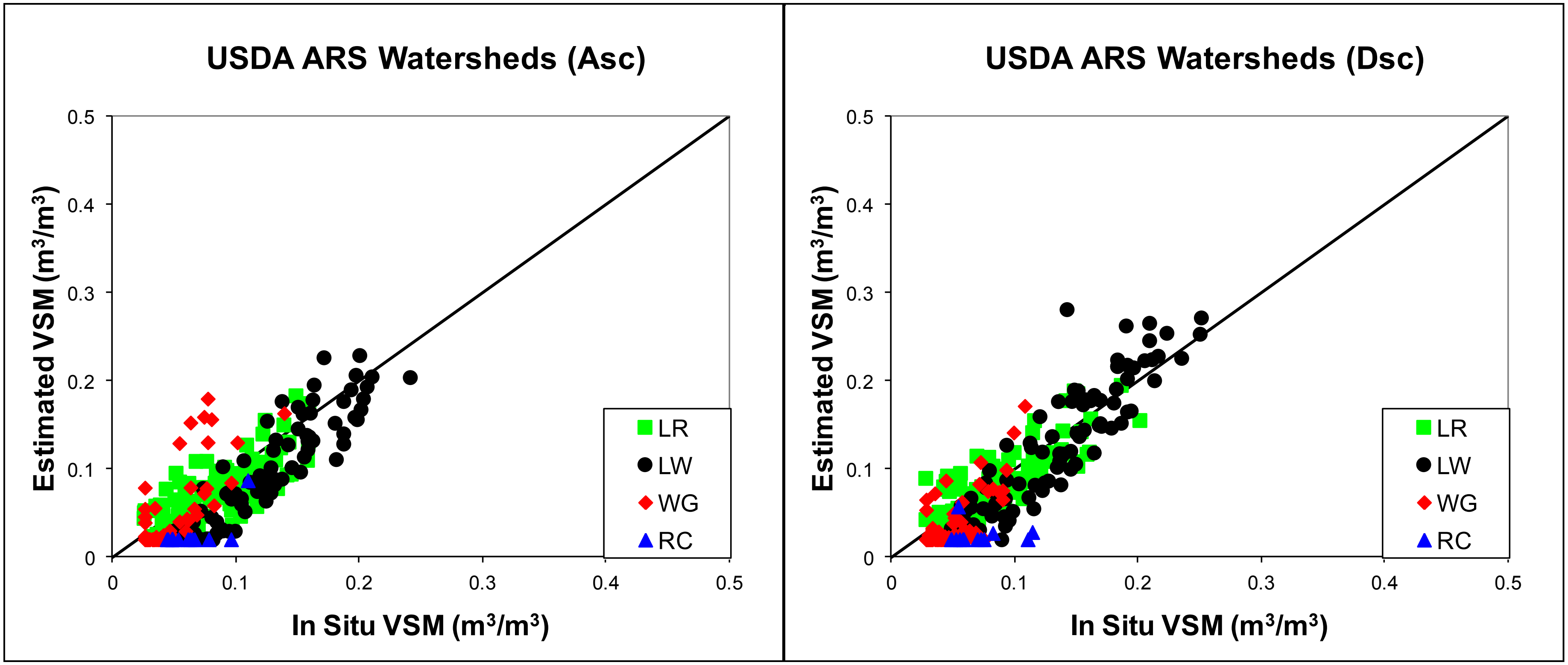
Evaluation of SMAP L2 Algorithm Using SMOS



SCA (SMOS) (h-pol) – Watershed Results



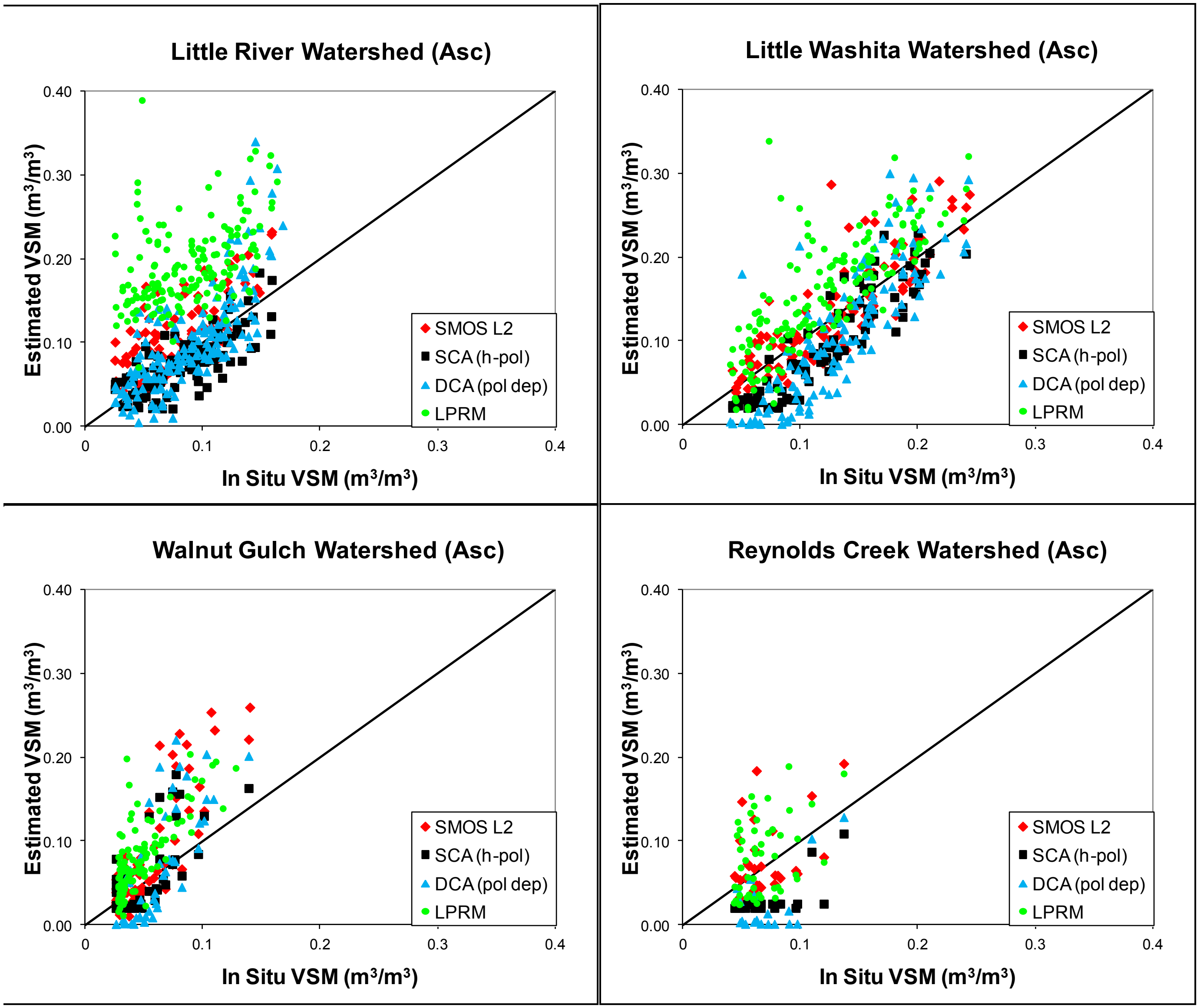
- Good range of observed soil moisture conditions
- SCA (h-pol) results compare well with in situ observations
- Dsc (6:00 PM) results are satisfactory

SCA (SMOS) – Watershed Results

Watershed	Ascending				Descending			
	RMSE	Bias	R	N	RMSE	Bias	R	N
Little Washita, OK	0.037	-0.027	0.913	88	0.034	-0.007	0.904	92
Little River, GA	0.026	-0.009	0.752	97	0.024	-0.001	0.798	88
Walnut Gulch, AZ	0.027	-0.004	0.764	85	0.022	-0.012	0.733	95
Reynolds Creek, ID	0.039	-0.037	0.681	30	0.051	-0.045	0.346	26
RMSE (Root mean square error), and Bias are in m^3/m^3. R=Linear correlation coefficient, N=Number of samples								

- Low bias and RMSE for LR and WG (asc)
- Underestimation bias and low correlation for RC.
- Most of the error for LW and RC is due to dry bias.
- The sample size is small due to removal of the extended FOV TBs that results in a repeat cycle of about 9-10 days.

Watershed Results



- H pol better over LR and WG
- LPRM has a wet bias
- LPRM and DCA have higher scatter
- SCA (h-pol) closest to the 1:1 line
- Vegetation parameters need to be polarization specific

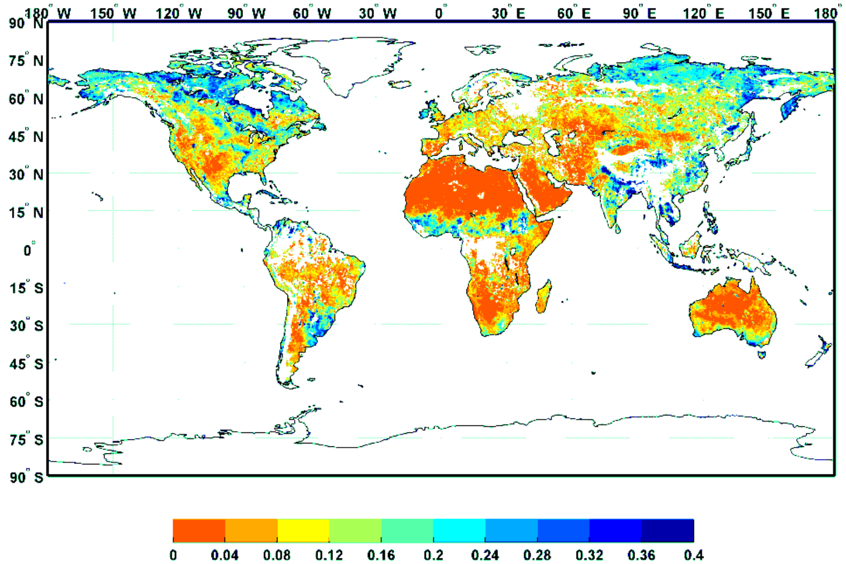
Summary Statistics

Algorithm	Ascending				Descending			
	RMSE	Bias	R	N	RMSE	Bias	R	N
SMOS L2	0.042	0.017	0.776	306	0.038	0.006	0.769	301
SCA (h-pol)	0.032	-0.016	0.796	300	0.029	-0.008	0.773	288
SCA (v-pol)	0.033	-0.011	0.812	295	0.032	0.001	0.774	283
DCA (pol-ind)	0.078	0.051	0.672	402	0.074	0.056	0.701	335
DCA (pol-dep)	0.049	-0.002	0.769	355	0.053	0.006	0.734	237
LPRM	0.076	0.057	0.658	335	0.121	0.078	0.608	402
RMSE (Root mean square error), and Bias are in m^3/m^3. R=Linear correlation coefficient, N=Number of samples								

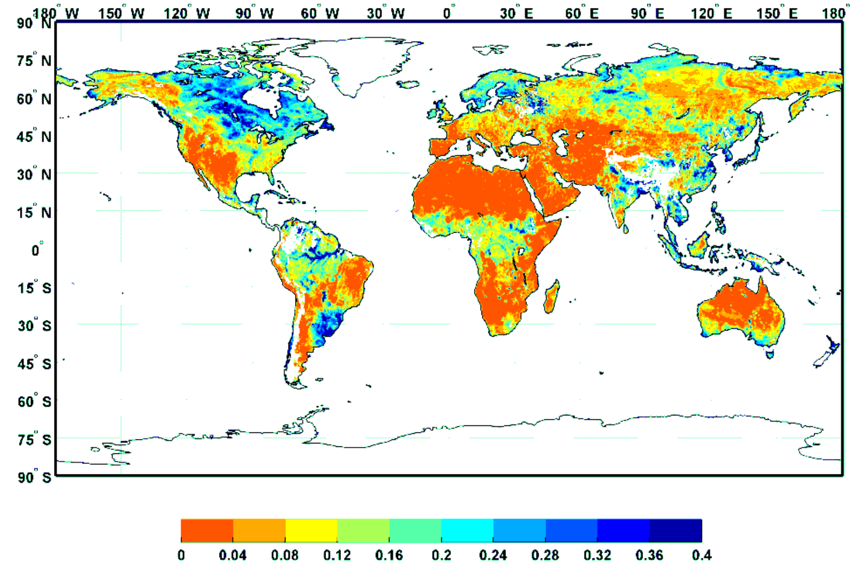
- SCA (h-pol) consistently performs better than other options
- SCA algorithm have lower RMSE
- Vegetation parameters need to be polarization dependent
- SMOS L2, SCA (h-pol) and SMOS (v-pol) algorithms meet the accuracy requirements

Global Results for July 1-10, 2011

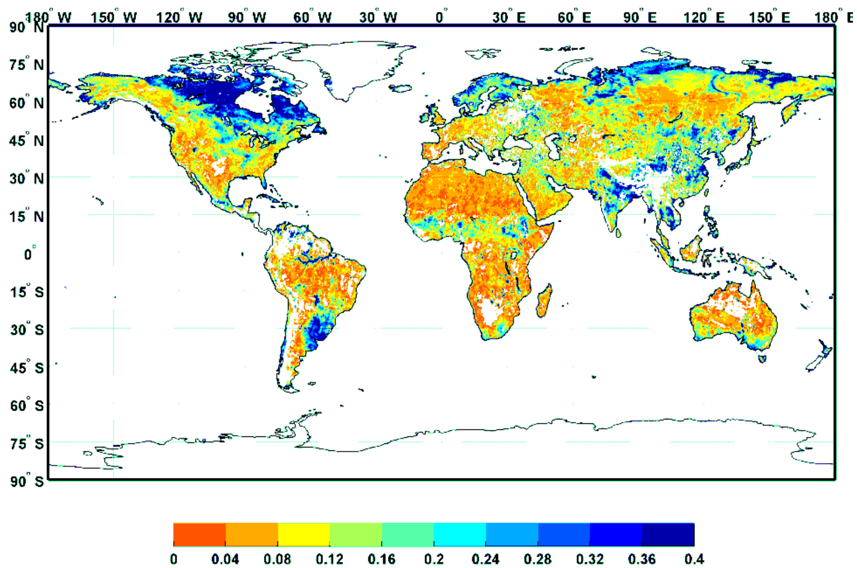
SMOS L2



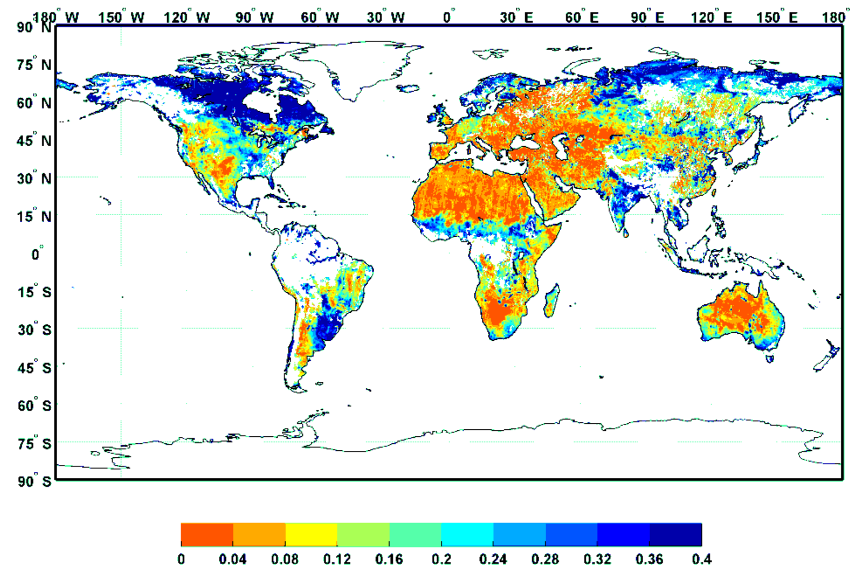
SCA (h-pol)



DCA (pol dependent)

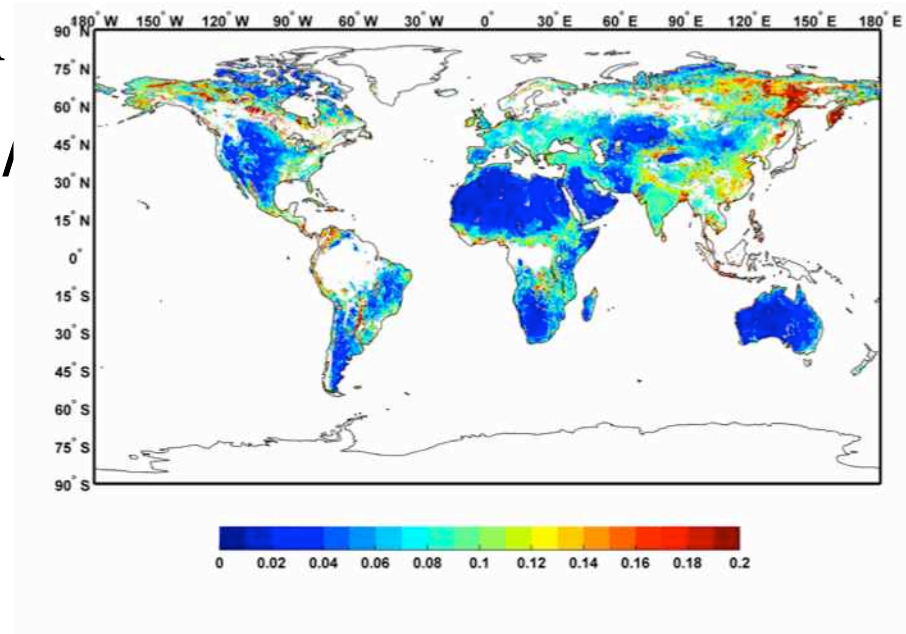


LPRM

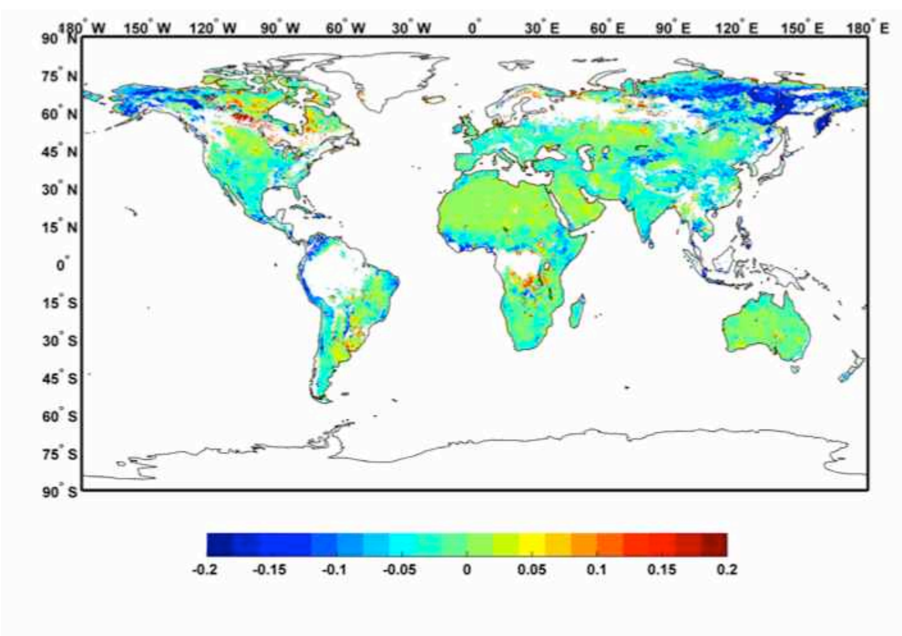


Comparison between SMOS L2 and SMOS/ SMAP

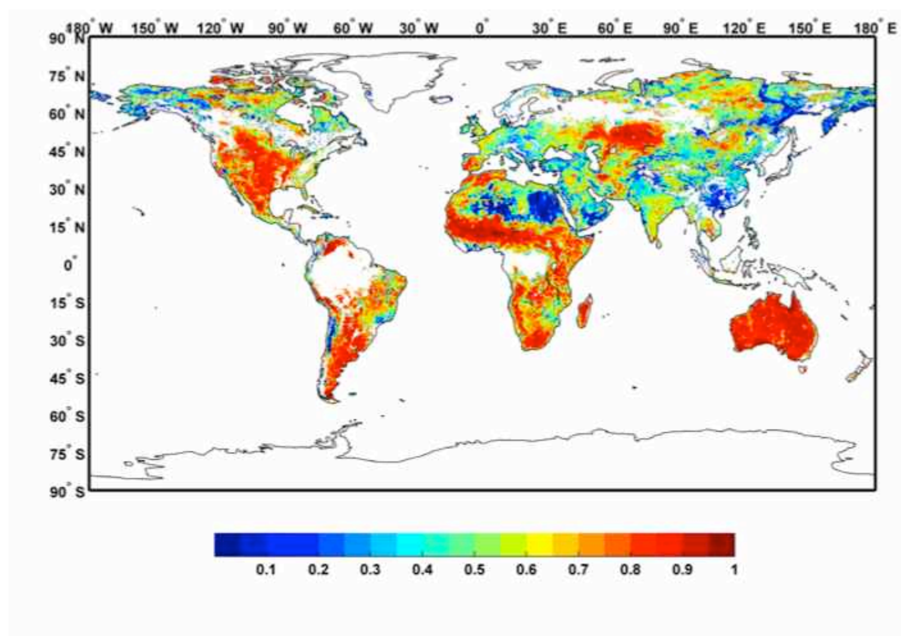
RMSD



Bias (SMOS/SMAP-SMOS L2)



Correlation Coefficient



Comparison between SMOS L2 and SMOS/SMAP

IGBP	**Land Cover**	RMSD	R	Bias	Count
1	Evergreen needleleaf forest	0.1707	0.3919	0.0822	146468
2	Evergreen broadleaf forest	0.1997	0.4217	0.0395	8667
3	Deciduous needleleaf forest	0.1186	0.4567	-0.0755	728238
4	Deciduous broadleaf forest	0.0934	0.6176	0.0124	106302
5	Mixed forest	0.1923	0.368	0.1135	91462
6	Closed shrublands	0.0773	0.6601	-0.0276	1828716
7	Open shrublands	0.077	0.7335	-0.0246	19937818
8	Woody savannas	0.0944	0.6162	-0.02	8308739
9	Savannas	0.0696	0.7414	-0.0238	7842089
10	Grasslands	0.0636	0.7794	-0.0126	10696198
11	Permanent wetlands	0.1519	0.6059	-0.0114	369779
12	Croplands	0.0885	0.6553	-0.0201	11243691
13	Urban and built-up	0.1268	0.5643	0.037	167625
14	Cropland/natural vegetation mosaic	0.1025	0.6546	-0.0472	2819540
15	Snow and ice	0.0996	0.4599	-0.0124	241604
16	Barren or sparsely vegetated	0.0438	0.5799	0.0096	20445975
	Overall	**0.0739**	**0.727**	**-0.0145**	**84203903**

SMOS/SMAP data

- SMOS/SMAP product was successfully validated using USDA watersheds
- The SMOS/SMAP product should be validated over a wider set of validation sites
- Need to perform a rigorous comparison between different SMAP L2_P algorithms: Critical for algorithm selection.
- SMOS/SMAP data product will provide real world simulated SMAP radiometer observations and soil moisture product
- SMOS/SMAP data will be compared with SMOS, AMSR-E/GCOM-W and Aquarius data products

SMAP and SMOS/SMAP Data Products

Data Product Short Name	Short Description	Gridding (Resolution)	Latency*
L1A_Radar	Radar raw data in time order	-	12 hours
L1A_Radiometer	Radiometer raw data in time order	-	12 hours
L1B_S0_LoRes	Low resolution radar σ_o in time order	(5x30 km)	12 hours
L1B_TB	Radiometer T_B in time order	(36x47 km)	12 hours
L1C_S0_HiRes	High resolution radar σ_o (half orbit, gridded)	1 km (1-3 km)**	12 hours
L1C_TB	Radiometer T_B (half orbit, gridded)	36 km	12 hours
L2_SM_A	Soil moisture (radar, half orbit)	3 km	24 hours
L2_SM_P	Soil moisture (radiometer, half orbit)	36 km	24 hours
L2_SM_A/P	Soil moisture (radar/radiometer, half orbit)	9 km	24 hours
L3_F/T_A	Freeze/thaw state (radar, daily composite)	3 km	50hours
L3_SM_A	Soil moisture (radar, daily composite)	3 km	50 hours
L3_SM_P	Soil moisture (radiometer, daily composite)	36 km	50 hours
L3_SM_A/P	Soil moisture (radar/radiometer, daily composite)	9 km	50 hours
L4_SM	Soil moisture (surface & root zone)	9 km	7 days
L4_C	Carbon net ecosystem exchange (NEE)	9 km	14 days

* Mean latency under normal operating conditions (defined as time from data acquisition by the observatory to availability to the public data archive). The SMAP project will make a best effort to reduce these latencies.

** Over outer 70% of the swath.

Data Processing Lessons Learned

- AMSR-E went through 10 public data releases
- SMOS has been through 5 public data releases
- Aquarius has been through 8 complete internal re-processings (expected to be 10 at the end of cal/val period)
- **Need for a through and cautious approach**

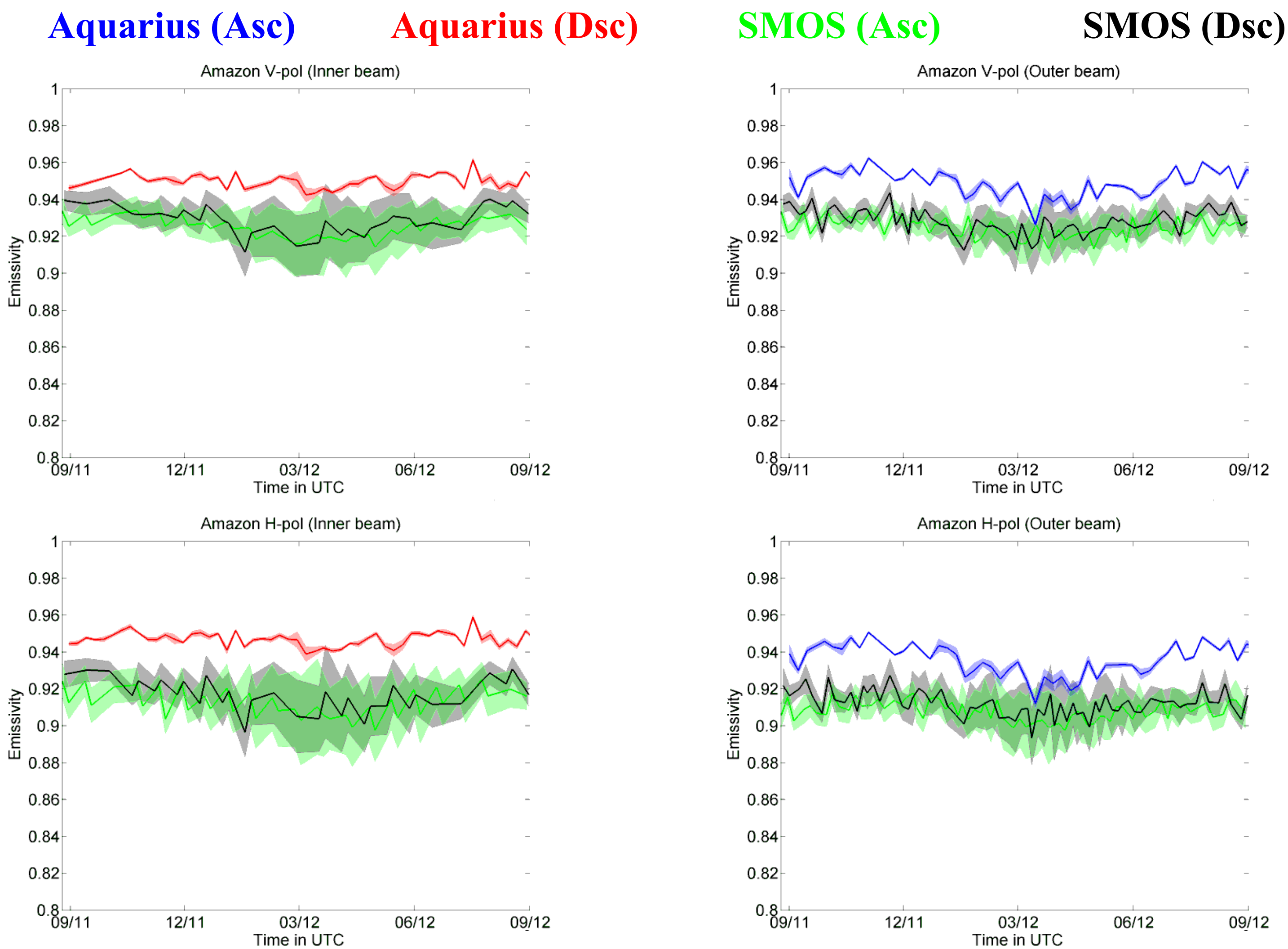
L-band observations over Vicarious Targets

Objectives

- Need for consistent observations:
  - Vicarious targets provide an independent calibration site
  - Vicarious targets can be used to calibrate multiple satellites
  - Critical to develop a long-term climatic data record of L-band brightness temperature observations
  - A physical algorithm for development of a long term environmental data record that spans multiple L-band missions requires consistent input observations

Vicarious Targets

- Amazon
  - Hot target
- Dome-C
  - Stable cold target in Antarctica
    - ESA has done extensive studies over this location.
    - Multi-year field experiment with a ground based radiometer (RADOMEX)



- Surface temperature effects eliminated by the use of land surface emissivity (NCEP surface temperature)
- Very little difference in Asc and Dsc observations over Amazon
- H and V pol observations are similar
- TB and emissivity does not change with incidence angle for both h- and v-pol
- Variability – Aquarius has higher stability (lower St. Dev.)
- Consistent difference between Aquarius and SMOS observations

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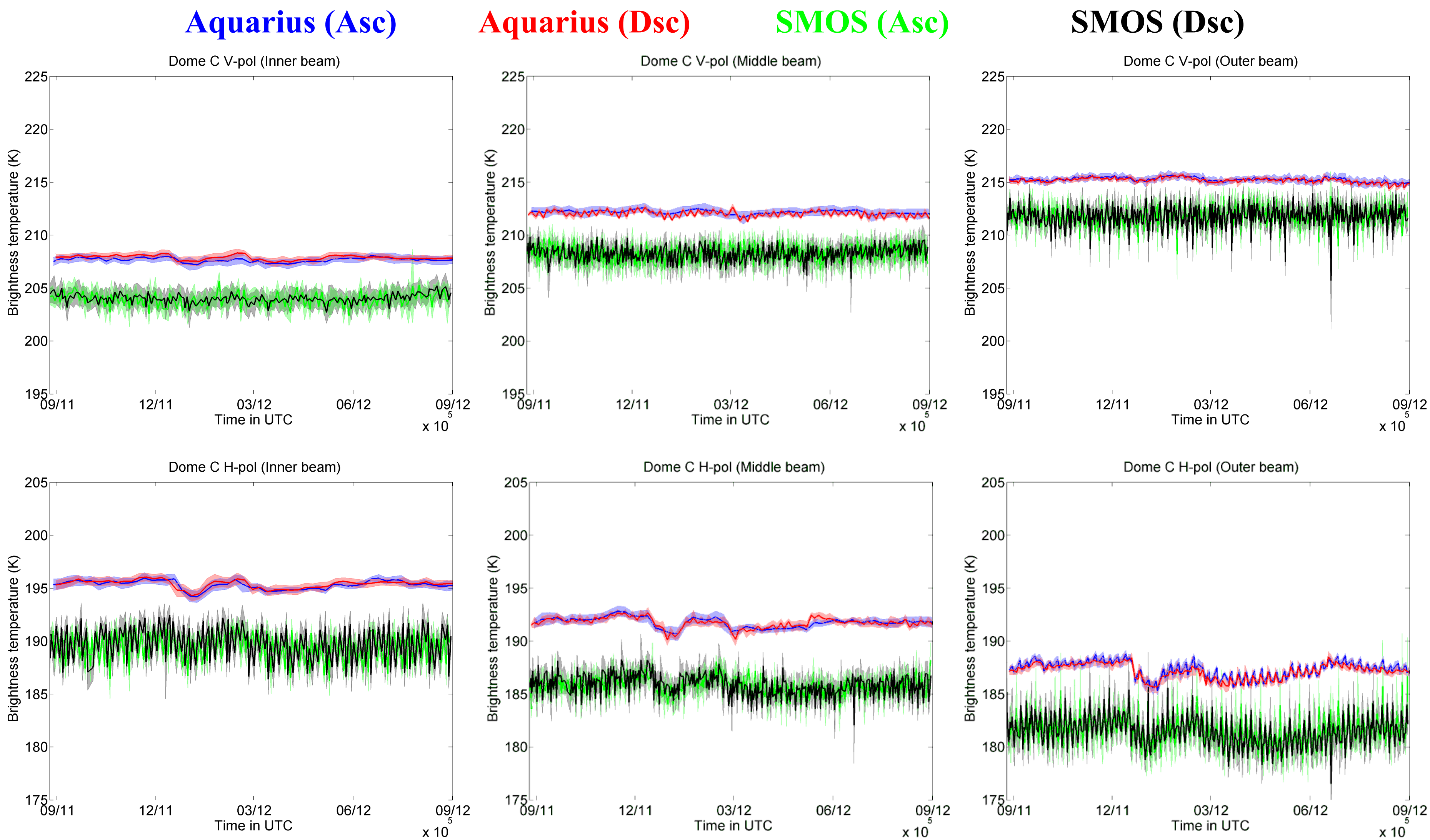
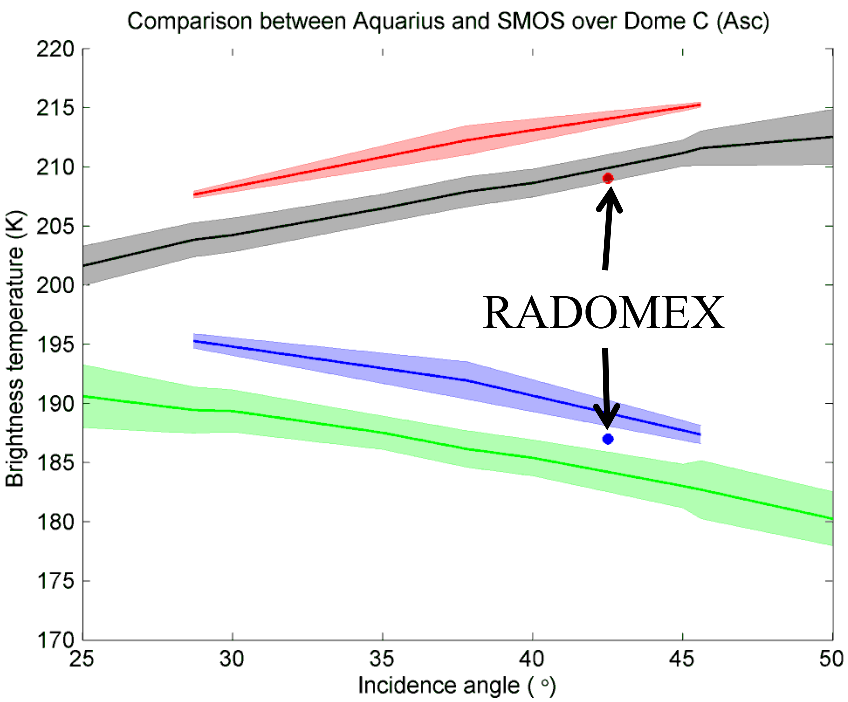
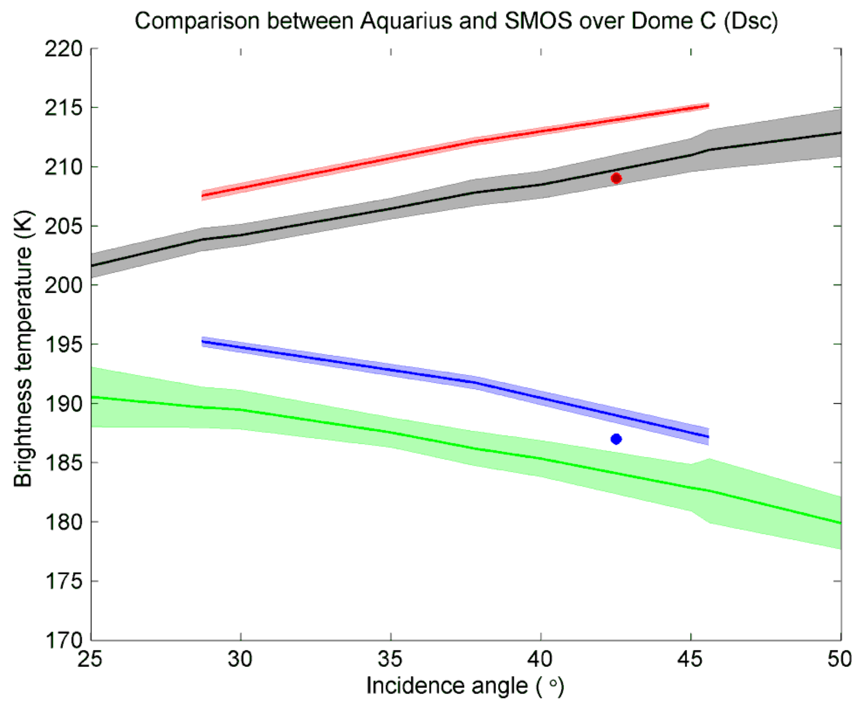


- Very little difference in Asc and Dsc observations over Dome-C
- Variability – Aquarius has higher stability (lower St. Dev.)
- V pol observations higher than h pol for both satellites
- TB increases with incidence angle for v-pol and vice versa for h-pol
- Bias between Aquarius and SMOS observations

Multi-platform Dome-C observations





Aquarius (h-pol) **Aquarius (v-pol)** **SMOS (h-pol)** **SMOS (v-pol)**

Summary

- Aquarius observations very stable over Dome-C
- Very little variability in Aquarius observations over Dome-C
- SMOS observations lower than Aquarius observations for all channels